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Are biofuels an efficient technology for generating sustainable development in oil-dependent African nations? A macroeconomic assessment of the opportunities and impacts in Burkina Faso

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ABSTRACT

This paper discusses the opportunity for substituting fossil fuels with biofuels in a Sahelian country, Burkina Faso. Bearing in mind the strong link between energy and development, and given the country's heavy reliance on imported fossil fuels, our study showed that the overall economy (private and public companies and basic social services) and the State Budget could be seriously affected if no viable and local alternative is integrated into the national energy strategy. In view of local potential, it is recommended that adequate energy resources be sought in order to ensure sustainable socio-economic development. Biofuel opportunities are discussed taking into account technical, agronomic and land potentials in this country. Diversification of energy resources with biofuels would substantially reduce fuel imports in the short term, improve overall public finances, provide a chance to develop agriculture and provide benefits for the locals. However, if they are to generate development, biofuel projects need to be mindful of food security and economic incentives, and should be part of national agricultural strategies.

Contents

1. Introduction 2200
2. Energy and development in Burkina Faso 2200
   2.1. Country overview: a poor country relying on extensive agriculture 2200
   2.2. Energy supply 2201
   2.3. Fossil fuel consumption and prospects for substitution 2201
3. Macroeconomic impacts of fossil fuel imports for Burkina Faso 2201
   3.1. Oil price structure and impacts of imports on the Budget 2202
   3.2. Impacts of fossil fuel imports on the national economy 2202
4. Biofuel potentials and risks for Burkina Faso 2203
   4.1. Technical potentials 2203
   4.2. Agronomic potentials 2205
   4.3. Land potentials and competition 2205
   4.4. National policy framework for the development of biofuels 2206
5. Positive impacts and limitations 2206
   5.1. Socio-economic and environmental impacts 2206
   5.2. Profitability of biofuels 2207
   5.3. Impacts on macroeconomics 2207
6. Conclusion 2207
   References 2208

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1. Introduction

The World Commission on Environment and Development suggests that development is sustainable where it "*meets the needs of the present without compromising the ability of future generations to meet their own needs*" [1]. In addition, energy has been defined by the United Nations Development Programme (UNDP) [2] as playing a key role in sustainable development and poverty alleviation efforts. As specified in the energy objectives [3] of the New Partnership for Africa's Development (NEPAD), ensuring the provision of adequate, affordable, efficient and reliable high-quality energy services with minimum adverse effects on the environment for a sustained period is crucial for African countries. Although there are no specific Millennium Development Goals (MDGs) [4] relating to energy, it will be impossible to achieve MDGs without improving the quality and quantity of energy services in the developing world [5,6]. It affects all aspects of development including livelihoods, incomes (MDG 1), access to water, agricultural productivity, health (MDG 4 and 5), education (MDG 2 and 3), and gender related issues [7].

Many studies [5,8–10] have shown the net positive link between energy consumption and development. For example, the African Energy Policy Research Network has demonstrated (see Fig. 1) the correlation between Gross National Product (GNP) and per capita energy use in Africa [11].

While energy is not the sole factor for sustainable development, Africa needs to improve reliability and to search for more abundant, cheap energy in order to enable economic growth [12] and ensure the well being of its populations. It also needs to reverse environmental degradation and health impacts that are associated with the use of traditional fuels in rural areas [13,14].

Energy generates electricity for a variety of applications, including domestic purposes, off-grid rural electrification, small and medium enterprises and industrial needs. Roughly 1.6 billion people, mostly in developing countries, are reported as lacking access to basic electricity services. The lack of electricity deprives people of basic necessities such as refrigeration, lighting, and communications, and undermines national competitiveness [15]. Furthermore, most African countries are highly dependent on fuel imports [5]. World oil reserves are being depleted at an unprecedented rate, placing considerable pressure on the economies of oil-importing African countries in particular, and threatening their economies. Since the 1973 oil price shock, the prices of crude oil-based fuels have increased sharply, sometimes requiring as much as 20 percent of national income in Sahelian states [16]. Recently, fuel prices have become even more unstable and have increased very sharply (up to US$ 70 in late 2006 and almost reaching US$ 150 in mid-2008) [17]. According to the International Monetary Fund, Heavily Indebted Poor Countries (HIPC) are among the most seriously affected by higher oil prices [18]. These countries are already running large current account deficits and will encounter a significant deterioration in their foreign trade balance. Since oil is a finite resource, petroleum prices will inevitably escalate when this resource becomes limiting [17,19,20]. This situation weighs heavily on the assessment of public finances, at the expense of public services and oil-consuming businesses. Moreover, a lack of energy availability, or excessive energy prices, means a lack of basic social services, namely healthcare, education, drinking water supplies and nutrition, as well as difficulties in developing productive activities, particularly those related to the promotion and processing of agro-pastoral products [15,21].

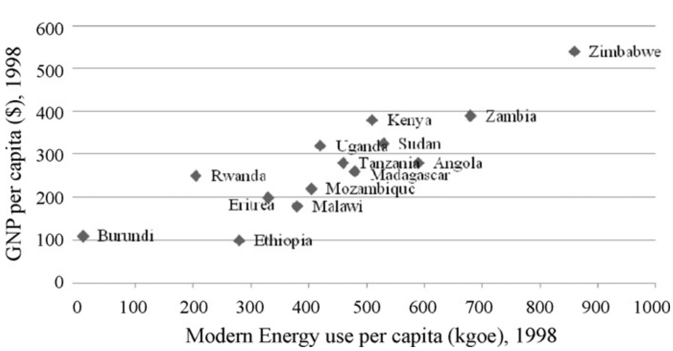


Fig. 1. Modern energy use per capita (kgoe) vs GNP per capita ($) [9,11].

In order to decrease reliance and pressure on fossil fuels, a number of countries, like Burkina Faso, have started to look closely at biofuels [22] for creating a more secure supply, in a less volatile market that can be accessed domestically [23]. Biofuels are increasingly seen as one of the best fuel resources that almost any country with surplus land and labour resources can exploit through relatively low capital inputs and medium levels of management.

Thus, this creates an attractive opportunity for biofuels to boost the development of national industry and to increase incomes in rural areas, by generating new energy sources and new channels in the agricultural sector. Given the challenges, developing crops for biofuel production seems worth exploring for these countries, while taking into account the country's agricultural and land situation and understanding the socio-economic and environmental impacts (deforestation, competing land uses, use of chemicals and fertilizers, etc.) [24].

This paper presents a macroeconomic assessment of the opportunity of biofuels, in order to study whether it is an efficient technology for generating sustainable development in oil-dependent African nations. The case study will focus on the consequences of fuel energy prices on a national level in Burkina Faso, one of the poorest countries in the world, heavily dependent on fossil fuel imports. In this country, only 5% of households have access to electricity, compared to 20% in the West African region [5].

The paper presents an economic appraisal of the country's vulnerability to oil fluctuation and takes a closer look at the potential biofuel strategy, considering the effects of large-scale programmes on land use, food security and socio-economic development. Finally, it sets the context for further discussions on biofuel feasibility in Burkina Faso.

2. Energy and development in Burkina Faso

2.1. Country overview: a poor country relying on extensive agriculture

Burkina Faso, landlocked in the middle of West Africa, is one of the poorest countries in the world with a Human Development Index (HDI) ranking it 177th out of 182 countries in 2007 [25]. People living below the poverty line (established at € 111/year) amounted to 46.4% in 2003 [26], and that percentage is increasing despite all the national measures and international help (1994: 44.5%, 1998: 45.3% [27]), with a greater incidence of poverty in rural and peri-urban areas.

The country covers 274,000 km^2 in the Sudano-Sahelian zone with an estimated population of more than 14 million people [28], largely farming and pastoral rural communities, while only 20% live in urban areas (10% in the capital city Ouagadougou). The country is one of the most populated in the West African region, with a strong increase in urban inhabitants, more than three times that of the rural increase [29]. Taking a population growth rate of 2.4%, the overall population will double in 29 years [29]. Agricultural activities account for more than one third of GDP, and provide jobs and income for about 80% of the population [27], with cotton being the main cash crop [29]. As Africa's leading cotton producer Burk-

ina Faso mostly relies on that crop: 6 out of 14 million Burkinese are exclusively dependent on cotton, which accounts for 60% of national export earnings [29,30]. Cotton is followed by peanut, shea nut, sesame, cow pea, sorghum, millet, corn and rice farming.

The overall economic performances of the country are linked to agricultural activities [29], which are highly unpredictable and dependent on climate fluctuations. The country is in a transitional area, characterized by large rainfall variations and high susceptibility to drought. The land, cellulose resources and water are irregularly distributed and managed with low sustainability.

Moreover, the Intergovernmental Panel on Climate Change (IPCC) described Africa as the region most vulnerable to the impacts of projected climate changes [31]. Because poverty limits adaptation capabilities, agricultural systems are particularly vulnerable [32]. Only a few reliable facts exist on West Africa concerning the extent and the consequences of climate change, but the IPCC forecasts a greater increase in temperature compared with other regions, and consequently probably more extreme climatic events (drought and flooding) [33].

Despite all of these constraints, Burkina Faso's GDP (5.697 million US$ in 2005) grew by an annual average of 5% from 1994 to 2004 and by 7.5% in 2005 (inflation rate at 6.4%) [29]. However, despite many government efforts and international help to improve socio-economic conditions, the economy has remained singularly vulnerable. The overall economic performances also face a difficult domestic and international environment. Indeed, in 2007, the economy had to cope with high petroleum prices, and international decrease in exported raw material prices, mainly cotton, the depreciation of the dollar and poor agro-climatic conditions linked to climate change [34]. This situation impacted on economic growth, which stood at 3.6% in 2007 as opposed to 6.1% in 2006 [34]. In 2008, the country faced a food crisis and persistently high oil prices, demonstrating the country's vulnerability to internal and external factors.

Thus, national sustainable development has to involve the agricultural sector substantially, in order to empower the large majority of the workforce (80%). One of the big challenges facing the country is truly related to agriculture. Currently, this agriculture is suffering from a lack of mechanization and does not ensure food security for the country each year [27]. The objective of the government is to increase farmer production by 5–10% per year, in order to limit food imports, and increase income levels by 3% per person per year [34]. The two current priorities of the Government are therefore agricultural intensification and diversification [35]. Agricultural intensification particularly calls for mechanization and better access to energy. Another complementary way to improve food security and income generation is to develop agricultural production through processing. It also requires better access to energy in order to develop agro-processing. Consequently, the development of biofuels in Burkina Faso is consistent with the objectives of agricultural diversification and intensification, as well as agricultural product processing.

2.2. Energy supply

The main characteristics of Burkina Faso's energy sector are (1) low consumption levels, (2) predominance of traditional energies, (3) poor access to electricity, (4) modern energy prices that are prohibitive for the population, and (5) heavy dependence on imported fossil fuels, which exerts pressure on the commercial balance. Burkina Faso's energy poverty is illustrated by the low level of fossil fuel consumption, which amounts to the equivalent of 275 l of petrol per inhabitant per year [36], equivalent to 2 or 3 steres of wood, and the ultimate energy consumption amounts to 234 kgoe/inhab. This figure is drastically low compared with other final energy consumptions: 1145 kgoe/inhab worldwide, 5418 in the United States and 454 on average in the CEDEAO countries [5].

Burkina Faso has few natural energy resources: no petrol, no coal, limited hydraulic potentials, and over degraded woody resources. There is a direct link between poverty and the use of traditional biomass, where a large proportion of people living on less than $2 a day use traditional biomass as their energy source [13]. Indeed, biomass accounts for over 89% of the country's energy consumption. This biomass is distributed between fuel wood (91%), crop residues (5%), bagasse (3%) and charcoal (1%) [37]. This has led to over-exploitation of forests by rural communities to cover their energy needs.

As a landlocked country, almost all imported goods arrive at the ports of Cotonou, Abidjan or Lome and have to cross by land through Benin, Ivory Coast and Togo respectively. So, Burkina Faso is doubly impacted by rising oil prices: the purchase of the barrel and coastal storage, with transportation costs that depend on fuel prices are responsible for an extra cost of 30% compared to CAF prices [38].

In addition, only 5% of households in 2008 had access to electricity [5], with an access rate below 1% in rural areas [29]. In 2008, electricity imports from Ivory Coast and Ghana amounted to 18% of national consumption, while the national company supplied 64% of electricity consumption from thermal power stations using imported fuel, and 18% from hydroelectricity centres [39]. In the near future, the strategy of interconnection [36] with foreign countries will be extended to 80% of national consumption within 5 years, while national thermal production will only amount to 20%. This will greatly increase dependence on neighbouring countries for energy delivery, especially from Ghana and Ivory Coast.

2.3. Fossil fuel consumption and prospects for substitution

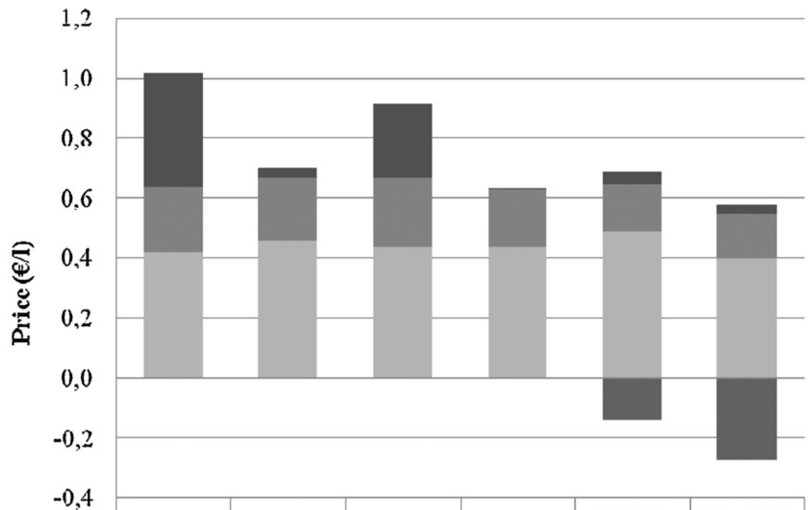
Imported fossil fuel is the second largest source of energy, behind wood resources, with 16% of consumption. From 1993 to 2007 overall fossil fuel consumption was almost multiplied by 3, in line with the development of electricity demand and the increase in fuel demand from the vehicle pool. Oil is mainly used for transport (63%) and electricity production in national thermal power stations (23%) [38].

Fossil fuel imports amounted to 522,000 TOE in 2007, weighing heavily on the country's trade balance, as fossil fuel consumption amounted to more than 50% (around € 332 million in 2007) of the national trade balance [36]. Given the increasing price of fuel and growing energy needs, this dependence exerts strong pressures on the country's economy. However, according to the regional electricity integration policy, interconnected grids would provide solutions for cheaper power supplies for the medium and long terms. However, to ensure the security of supplies, a thermal production supply using at least 20,000 t of oil will remain [22]. According to the Ministry of Mines, Carriers and Energy, the electrification (and mechanization) of rural areas would create increasing demand for hydrocarbons, rising to 50,000 t in 2020 [22]. For transport energy, the current consumption of 350,000 t in 2010 would reach 680,000 t in 2020 [22].

The increase in fuel prices, essentially consumed for transport and electricity production, leads to (1) an increase in energy costs for households, the State and companies, (2) limited development of electrification, particularly in rural areas, and (3) overconsumption of woody resources in the country.

3. Macroeconomic impacts of fossil fuel imports for Burkina Faso

As a net oil importer, Burkina Faso will be among the African countries most seriously affected by higher fossil fuel prices,



	Super 91	Paraffin	Gasoil	DDO	DDO Sonabel	Fuel Oil Sonabel
Taxes	0,380	0,030	0,250	0,003	0,040	0,030
Channels	0,220	0,210	0,230	0,190	0,160	0,150
CAF Price	0,420	0,460	0,440	0,440	0,490	0,400
Subsidy					-0,140	-0,270

Fig. 2. Oil product price structure in euros (€) (January 2008) [42].

because of very low per capita incomes, high levels of fuel imports relative to GDP, large current account deficits and a high external debt [40].

The price trends for fossil fuels imported into Burkina Faso show the importance of State price policy. Some products are a major source of taxes, hence of earnings for the Budget, whereas others benefit from the social support of prices. Fossil fuels and their derivatives are spread throughout the Burkinese economy, but some industries are more sensitive than others to fuel prices.

3.1. Oil price structure and impacts of imports on the Budget

Oil prices are high and increasing. Prices for consumers already increased by 60% from 1995 to 2007 [41] and the average cost of electricity production rose by 40% over the last 4 years. Moreover, imported fuels in Burkina Faso cost 30% more than the CAF price due to storage in coastal warehouses and road or rail transport (which are directly indexed to the price of a barrel, so are expected to increase as well) [38]. This snowball effect is increasing the overall prohibitive access to energy.

According to a ministerial by-law [38], prices are administered according to the port of arrival, the haulage fees, and rental for storage. All products are subject to customs levies and taxes, with taxes on petroleum products and VAT for diesel fuel and petrol only. As shown in Fig. 2, subsidies are only given to oil products for electricity production (€ 0.145/l for DDO and € 0.27/l for fuel oil) [42]. They aim to give access to electricity at an affordable price for consumers.

In view of Fig. 2 and Table 1, diversifying oil with biofuels for electricity production would automatically reduce the subsidies granted to the national electricity production and distribution company for oil products. However, concerning the transport sector, the substitution of fossil fuels with biofuels would be a major source of financial losses for the State, as taxes are quite high, and petrol, fuel oil and DDO used for transportation represent more than 60% of national oil imports. The State raises € 27 million annually from imports of oil products (based on year 2004, current price), amounting to 41% of total import taxes, all sectors combined [43]. Subsidies only concern the fuels for Sonabel, but they reached a high amount of € 29 million in 2007, despite a State decision in 2006 setting the maximum amount of subsidies at € 23 million per year [38]. All in all, the total annual in taxes is nearly equivalent to the subsidies, so interventions nearly cancel each other out. Consequently, the substitution of fossil fuels would not impact so much on the State Budget.

3.2. Impacts of fossil fuel imports on the national economy

Oil prices are rising faster than for other goods and services: between 1998 and 2008, on the retail markets in Ouagadougou, the

Table 1
Oil product use and proportions in Burkina Faso [38].

Oil product	Petrol	Paraffin	Gasoil	DDO	Fuel Oil Sonabel
Ratio (%) in oil product imports[a]	30	5	31	11	16
Use	100% for transport	100% for rural lighting	94% for transport 5% for electricity	20% for transport (train) + 80% for electricity	100% for electricity in thermal power stations

[a] NB: calor gas and kerosene are not taken into account considering their low contribution to the oil import mix.

price of white sorghum increased by 11.7%, bread by 7.5%, beef by 49.8% and fossil fuel by 128.5%. Thus, given the increase in the relative price of energy inputs, and without any energy diversification, there will be a rise in the national economy's production costs, in line with the energy dependency of activities. The National Accountancy tool called the 'Input–Output Table' (IOT) produced in 2000 [43] (year chosen because it included 43 activities instead of the 18 activities in a usual year) may help to measure the level of energy use for each activity of the domestic economy. By isolating the items 'fossil fuels' (imports) and 'transportation' (mainly national production, proxies of fuels), we first measured who uses these products, between national activities, households and exports, and then we disaggregated the level of use for these two products in national activity. Unfortunately 'electricity' is associated with 'gas and water' so it is impossible to isolate it. Finally, for each activity, it is possible to analyse the reliance on 'fossil fuels' and 'transportation', and consequently the impact of a high fossil fuel price on the national economy. The IOT shows that globally, the main users of 'fossil fuels' and 'transportation' products are economic activities (CFAF 68 billion for 'fossil fuels' and CFAF 75 billion for 'transportation'), followed by households (respectively CFAF 71 and 28 billion) [43]. Consumer dissatisfaction is already making itself heard with food price riots. However, with 25% of imported fossil fuels for national activities being used in 'transportation' [43], companies will be the first to be weakened by the increase in fossil fuels, given the direct and indirect level of integration of these products [6,44,45].

'Transportation' is mainly used by 'trade' (57%), 'public administration' (13%), 'transportation materials' (12%), 'health and social action' (3%), 'beverages' (2.8%), and 'glass, pottery, building materials' (2.8%) [46]. 'Fossil fuels' are mainly used by 'the production and distribution of electricity, gas and water' (20.5%), 'public administration' (18.9%), and to a lesser degree, 'trade' (6.3%), 'transportation materials' (6.2%), 'beverages' (3.9%), and 'grains and starch products' (3.5%) [46]. A few activities would be doubly affected by the increase in price, because of their substantial use of 'fossil fuels' but also 'transportation'. The main vulnerable activities are 'trade', 'production and the distribution of electricity', 'gas and water', but also 'public administration' [46].

Thus, in 2000, the State raised CFAF 18 billion of taxes on 'fossil fuel' imports but spent CFAF 13 billion on 'fossil fuels' and CFAF 10 billion on 'transportation' purchases [46]. So, as oil taxes are not that significant when compared to the expenses of its administration, the State itself has a direct interest in substituting other energy sources, to reduce the price of energy if possible, but mainly to procure a significant proportion of its energy at a cost that is independent of worldwide oil fluctuations.

Moving on, based on the same IOT [43], the indicators in Table 2 examine in greater depth the susceptibility of activities to 'fossil fuel' price increases. *Indicator A* calculates the proportion of 'fossil fuel' and 'transportation' consumption compared to the total value of production for the activity. *Indicator B* calculates the profit of the activity showing its capacity to absorb fossil fuel price increases. *Indicator C* calculates the contribution of the activity to the GNP of Burkina Faso showing the weight of the activity for the national economy. Lastly, *indicator D* calculates the contribution of the workforce involved in the activity compared to the total national workforce, showing the weight of the activity for national employment.

Based on Table 2, it is obvious that 'Production and distribution of water, gas, electricity' (27.7%), 'transportation' (19.4%), 'trade' (16.3%), but also 'health and social action' (14.9%), incorporate directly or indirectly a lot of 'fossil fuels' in their process. To a lesser degree so do 'grains and starch products' (8.4%), 'transport materials' (7.2%), 'public administration' (6.8%), 'education' (6.6%), 'glass, pottery building materials' (6.6%), 'beverages' (4.5%), 'machinery and other equipment' (4.5%), and 'chemicals' (4.4%). These activities will be the most penalized by an oil price increase because of their production cost structure. They could also be the first beneficiaries of a less expensive source of energy.

Some of these activities would have limited options for absorbing a variation in fossil fuel prices, because they will only have a small capacity to decrease their profits. Among the most vulnerable, there are some industries ('machinery', 'production and distribution of electricity, gas and water', 'chemicals', 'glass, pottery, building materials', etc.) but also, again, certain social activities such as 'education' and 'health and social actions' in particular.

'Health and social actions', which are extremely vulnerable to oil price fluctuations, are also highly creative of added value proportional to their production (more than 70%), even though this activity only contributes 1.1% of GNP. 'Beverages' and 'trade' too are highly creative of added value proportional to their production (84.8% and 67.2% respectively) and contribute a large share of GNP (5.2% and 11.2% respectively) but they are structurally more able to absorb a 'fossil fuel' price increase.

Lastly, even though more than 80% of workers are in agriculture, some activities with a substantial workforce and the capacity to create employment will be weakened because of their high incorporation of fossil fuels. These are 'trade' (0.9% of the total workforce), 'glass, pottery, building materials' (0.9%) and 'education' (0.5%). In fact, the basic social needs, such as health, water supply and education will be greatly weakened by fluctuations in imported fuel prices, as well as trade activities, which are essential to achieve economic progress. Moreover, the State, which is doubly impacted in its administration, has a major interest in reducing its fossil fuel consumption and its high fossil fuel reliance. If the national energy situation does not change, it could curb the country's development objectives.

In view of this global country and energy overview, and these macroeconomic consequences, the country and the government itself may be interested in the opportunities offered by biofuels to meet its energy needs and strengthen its development.

4. Biofuel potentials and risks for Burkina Faso

The major alternative energy resources abundant throughout the African continent are solar, biomass energy and a very little wind energy potential [16]. Given the national agriculture strategy [35], the large rural workforce in the agricultural sector, and the availability of land, the development of new agricultural activities for diversification of energy sources and expansion of locally produced energy are goals that can be satisfied by biofuels [13], also called "agrofuels".

4.1. Technical potentials

Biomass is the only renewable resource able to produce liquid fuel for engine applications. In order to meet the energy needs mentioned above, various biofuels could be produced in Burkina Faso with different characteristics, as described in Table 3. Among first generation biofuels, which are mature and applicable technologies, two main feed stocks can be utilized: sugar or starch based plants and oil-bearing plants [38]. Through the ethanolic fermentation of sugar-bearing plants, bioethanol can be produced to substitute petrol in petrol engines. However, based on the Brazilian experience, this technology is profitable with a minimum unified area of 20,000 ha sown with a sugar cane crop and the industrial process alone needs a lot of water (1 m^3/t) [47]. Moreover, petrol is only used for transport application in Burkina Faso [38], so bioethanol is not considered as a sustainable biofuel potential in the short term.

Table 2
Sensitivity of activities to fossil fuels, based on the Input–Output Table from Burkina Faso established in 2000 [43,46].

Activity (%)	Fossil fuels and transport/production (Ind.A)	Profit/production (Ind.B)	Added value/GNP (Ind.C)	Workforce/national workforce (Ind.D)
Subsistence crops	0.0	63.0	11.9	71.7
Cash crops	1.9	64.1	3.5	15.1
Farming	0.0	93.3	11.9	5.3
Forestry and hunting	0.0	88.6	1.7	0.3
Fishing, fish farming, aquaculture	0.0	87.6	0.3	0.0
Extractive industries	1.0	38.9	0.4	0.1
Slaughtering, processing and conservation meat and fish	0.0	29.6	2.0	0.0
Manufacture of fatty food	0.6	25.4	0.4	0.0
Processing of grains, manufacture of starch products	8.4	40.7	0.7	0.0
Food products from cereals	0.3	23.7	0.6	0.0
Sugar confectionary, chocolate, coffee processing. . .	2.8	−1.3	0.2	0.1
Manufacture of food products	0.6	51.6	1.8	0.1
Beverages industry	4.5	64.4	5.2	0.3
Tobacco industry	3.0	50.0	0.7	0.0
Shelling cotton, textile and clothing industry	2.3	8.7	1.0	0.2
Leather and luggage industry	2.3	11.9	0.1	0.1
Wood and straw industry	0.0	81.5	1.1	0.7
Paper, cardboard, publishing printing industry	0.3	71.8	0.4	0.0
Chemical products industry	4.4	28.9	0.2	0.0
Rubber and plastic products industry	1.7	15.1	0.1	0.0
Glass, pottery, building materials manufacture	6.6	28.8	1.0	0.9
Metallurgy, foundry, metal manufacture	1.6	38.0	0.7	1.8
Machinery and other equipment manufacture	4.5	4.8	0.0	0.0
Furniture making	0.8	28.2	0.1	0.1
Production and distribution of electricity, gas, water	27.7	19.2	1.2	0.0
Transportation materials construction	7.2	50.8	6.7	0.1
Trade	16.3	58.9	11.2	0.9
Repair	2.8	68.9	0.9	0.2
Accommodation and catering activities	0.7	17.8	2.1	0.0
Transportation	19.4	38.5	2.9	0.3
Postal and telecommunication services	1.6	50.0	1.7	0.0
Financial activities	1.5	36.1	1.3	0.0
Real estate activities	0.1	90.7	4.6	0.0
Services to companies	1.4	70.6	1.5	0.1
Public administration activities	6.8	48.5	16.4	0.3
Education	6.6	−6.0	2.1	0.5
Health and social action	14.9	21.5	1.1	0.2
Collective or individual services	1.0	54.5	1.1	0.4

Vegetable oils can be obtained by simple cold pressing of oil-bearing seeds and fruits. Raw Vegetable Oil (RVO) can be used in adapted diesel engines [48] or can be modified through a transesterification reaction with methanol to obtain biodiesel. Biodiesel is technically defined as a fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats [49]. Biodiesel is biodegradable, non-toxic and environment-friendly as compared to petrodiesel [50]. As shown in Table 3, as biodiesel has quite the same physico-chemical properties as diesel (same viscosity and cetane index) it can be used directly in all diesel engines, with an engine performance comparable to conventional diesel fuel [51], but it has to be produced by a costly industrial process. In adapted engines, RVO can be used as fuel without any problem: either through a dual fuelling system (preheating of the fuel before injection) or blending with diesel up to 30% [52]. Diesel engines are widely used in transport, electricity generation and shaft power. The strategy suggested in this paper is to produce simple and accessible local RVO for national basic needs, such as electricity and shaft power.

Table 3
Characteristics of biofuels applicable in Burkina Faso [38].

	Raw Vegetable Oil (RVO)	Biodiesel	Bioethanol
Production	Oil-bearing plants	Oil trans-esterification with methanol	Sugar or starch-based plants
Technology	Simple	Industrial process, mature for methanol etherification	Industrial process
Availability	From the village to industrial scale	Industrial scale	Industrial scale
Utilization	Mainly for static diesel engines (generators, mills, motor-pumps, etc.). The use of a bicarburation kit is recommended (cheap, simple and safe)	Any type of diesel engine (transport) It can replace 100%	With petrol engines in a mixture up to 10% for classic engines or up to 100% for specific engines (flex fuel). Only for transport application
Advantages	Easy and cheap	No need to modify engines	High octane index
Limits	Not suitable for transport Low cetane index and high viscosity Adaptation of the engine with dual fuelling system (0–100% RVO) or a mixture RVO/fuel under 30%	No methanol in west Africa Processes to produce biodiesel from ethanol not mature	Requires energy for distillation Only sugar cane use produces enough byproduct to generate the heat for the process Sugar cane plantations require a lot of water

Table 4
Jatropha curcas opportunities and risks as a raw material in RVO production [54,56,74].

Opportunities	Risks
No competition with edible plants	Very few reliable scientific data exist either for management or environmental assessment
Protection against soil erosion [56]	Perennial, needs three years to grow before production
May grow with little rainfall [57] and on marginal soils (associated with lower seed yields)	Oil cake toxic and can only be used as combustible solid
Tolerant to drought [74]	Needs fertile lands to grow better and competes de facto with food production
Can live up to 50 years	Impossible to predict the level of profitability in two or three years
Can produce biodiesel, soap and fertilizer [54,74]	

The advantages of RVOs are substantial because they are easy to produce with local assets and the vegetable oil could replace petroleum oil in two main applications: (1) in static diesel engines used in villages and (2) in the national thermal power stations for electricity. This second option could make it possible to replace 23% of the imported fossil fuels and thereby have a strong impact on the energy bill [38]. Application of this scenario may have substantial margins for expansion, because substitution could be up to 90% in the power stations, depending on the potentials and the supply of local oil. It could be flexible over time because it can be adjusted with the increasing level of RVO production in the country. Moreover, the national electricity company already has a bi-fuel kit in each power station, so no additional investment would be required in this development scenario. However, some quality standards need to be developed, but the Biomass and Biofuel Laboratory of the International Institute of Engineering, Water and Environment based in Ouagadougou is already working on it.

More and more developing countries are examining possibilities of substituting fossil fuels in the transport sector with locally produced biofuels [53]. The objectives are to create added value locally with RVO at an acceptable price compared to biodiesel, because no costly transesterification processes with imported methanol are required. It is, moreover, easier to produce RVO, and at an acceptable price, when compared to the current price of oil, which is usually the first barrier to biofuel production and competitiveness [53].

In fact, biodiesel requires an industrial process with methanol, a component derived from petroleum activities, which is unavailable in the country and in West Africa, and uncompetitive with the current price of a barrel of petroleum oil. Given the large amount of raw materials needed for industrial biodiesel and bioethanol production, we will focus on RVO.

4.2. Agronomic potentials

Many edible and non-edible oil-bearing plants are available and are already being cultivated in Burkina Faso, and could be cultivated to produce RVO. With the prevailing weather in Burkina Faso, the main plants potentially of interest for RVO production are *Jatropha curcas*, cotton, sunflower, peanut and soybean. In Burkina Faso, as edible oil crops are currently under-produced and food competition is a major concern, all biofuel project holders focus on non-food oil, although large-scale production of non-food oil crops requires land and labour, so may also create food competition.

J. curcas has attracted a lot of attention as a promising non-food oil producing plant that is highly adapted to marginal soils and arid to semi-arid conditions in tropical and sub-tropical countries [54]. Considering the large number of projects investing in *J. curcas* inside the country (more than 70,000 ha of plantations claimed in 2009 [22]), this plant could be a major raw material for the development of this scenario in the coming years. Plantations have been grown since 2007, in reaction to the European Union biofuels directive for promoting the use of biofuels for EU transport. The directive stipulated that national measures must be taken by countries across the EU aiming at replacing 5.75% of all transport fossil fuels with biofuels by 2010. On January 14th 2008, the EU cancelled its biofuels programme due to environmental and social concerns [55] (impact of biofuels on rising food prices, rainforest destruction, concern for rich firms driving poor people off their land to convert it to fuel crops, etc.). As a consequence, project holders in Burkina Faso have focused on local and regional potentials to sell their production.

As shown in Table 4, *J. curcas* is a plant with considerable potential. Plantations can prevent erosion and reclaim land. It can be grown as a live fence and under a wide range of rainfall regimes from 200 to over 1500 mm per annum [56,57]. Although *J. curcas* grows naturally in Africa, this plant is still in a very early stage of agronomic development on an industrial scale, and presents a number of risks, so research and experience have to be combined to improve a number of characteristics [17,56–58] (yield improvement and stability, reduction of toxicity, utilization of oil cake, etc.) and thus improve its economic competitiveness with hydrocarbons.

4.3. Land potentials and competition

Overall, there is high estimated biomass potential in sub-Saharan Africa, given the surplus production capacity linked to the existence of large rangelands that could be better managed [59]. More than 2/3 of West Africa's cultivable lands are not farmed, including 9 million hectares of irrigated lands [60]. However, local potential is very variable from one place to another.

On a country basis, the agricultural lands sown yearly in Burkina Faso accounted for approximately 45% of the cultivable potential in 2007, estimated at 9 million hectares [22], leaving large areas available for new crops. Irrigable lands are estimated at 165,000 ha, but only 12% are exploited [34]. In any case, the government wants to reserve them for food production only [22]. However, approximately 11% of lands in Burkina, mainly in the North of the country, were considered as seriously degraded in 2002.

In addition, energy access difficulties (mechanization, irrigation, etc.) constitute a major obstacle for the development of rural areas. Agricultural production is (i) family based: traditional small-scale farming with (ii) poor yield, average areas cultivated per unit of farm varying from 1.5 to 12 ha depending on the regions, and (iii) poorly equipped farms (in 2005, only 50% of farms benefit from harnessed culture) [29].

Given farming sector organization, and regardless of agronomic options, it is fundamental to prioritize family farming rather than industrial plantations. Although family farming requires more workers than industrial plantations (factor/ratio 1–10) [61], this is to minimize competition for land and even water resources and to promote and/or launch other cash crops. This strategy would contribute not only to reinforcing the rural world by organizing producer groups and/or processing cooperatives, but also to helping people procure energy services available from the village for shaft power, and up to industrial scale for electricity production.

However, biofuels may be risky for family farm organizations, because the development of new energy crops may increase the demand for land [62–65]. In a country facing food insecurity, it is essential to know the effects of competition between food-

Table 5
The land required to replace fossil fuels for electricity production.

Years		2008	2015	2025
Annual fossil fuel (fuel oil) consumption to produce electricity (t) [69]		71,148	26,723	16,834
Fuel Oil Net Calorific Value (NCV) (MJ/t) [75]			40,000	
Jatropha's NCV (MJ/t) [76]			33,000	
Jatropha's RVO yield (t/ha) in Burkina Faso [57]			0.4	
Ha necessary for the substitution of fossil fuel to produce electricity	30% substitution	64,680	24,294	15,304
	100% substitution	215,600	80,979	51,012
% of arable land in the country considering 100% substitution [22]		2.395	0.899	0.566

producing agriculture and new agriculture with a non-food purpose before developing biofuel crops [66].

J. curcas seed yield is still a difficult issue. Actually, the mature seed yield per ha per year is not known, since systematic yield monitoring only started recently. Earlier reported figures show a very wide range (0.4–12 t/ha/year) but are not coherent [57]. The large variations in yield come from the different types of cultivation conditions, from dry wasteland to good sites with high annual rainfall [57]. In Burkina Faso, yields in the fields are around 1 to 1.5 kg/tree with family farming. Seeds contain between 28% and 38% oil [67], corresponding to 300–500 l/oil/ha [68].

Thus, the question of competition between land for food or energy has to be taken into account regardless of the small territories necessary to substitute fossil fuels for national electricity demand. As shown in Table 5, given the productivity range for the possible biomass, more or less 9 million hectares of arable lands [22], no more than 2.4%, would be necessary up to 2025 to replace 100% of fossil fuels in the thermal power stations of the national electricity company.

National data on fossil fuel consumption have been forecast up to 2025, taking into account parameters such as demography and the increase in access and demand, but also the substantial interconnection strategy [69]. This strategy allows a very substantial reduction in oil imports (divided by 3) as early as 2010, when the first connection will start. Despite the importing of energy, fossil fuel consumption will then gradually evolve until at least 2025, returning to the same level of fossil fuel consumption as in 2009. Thus, the strategy to replace the oil used for electricity production by RVO may be possible from 2010, with a relatively gentle increase in the lands required, given that 70,000 ha of *J. curcas* are already planted. Moreover, in view of the available arable land in the country [33], the strategy is realistic from an agronomic and technical viewpoint (in 2005, only 36.7% of the available lands were being cultivated). Research and experience may help to improve agronomic data and choices, to achieve better yields with adequate plants and technical knowledge to allow better productivity and profitability, but also to gradually improve the level of substitution for electricity production.

In fact, substitution would enable the diversification of energy sources, a reduction in the dependency of the State, companies and households on fossil fuel products, diversification of crops and incomes for farmers, local rural investments and better access to energy that could enable agricultural intensification by mechanization and the promotion of crops through processing.

4.4. National policy framework for the development of biofuels

In view of the projected oil demand and the volatility of oil prices, Burkina Faso has decided to commit itself 'resolutely but reasonably' to a policy of promoting biofuels, announced at the International Biofuels Conference held in Ouagadougou in November 2009 [22].

Thus, the government will apply a maximum ceiling for lands reserved for energy production, which has been fixed at 500,000 ha corresponding to 5% of the total arable land (already 45% sown). The policy will promote traditional peasants' involvement in raw material supplies for national biofuel production earmarked for the domestic market. The Policy seeks to follow up and supervise the enthusiasm of developers and traditional farmers for *J. curcas*.

This policy will be accompanied by regulatory and tax measures to enhance the economic benefits of biofuel/hydrocarbon substitution, namely savings in foreign currency disbursements and the creation of added value on local and national levels, promoting the economic development of rural areas.

5. Positive impacts and limitations

5.1. Socio-economic and environmental impacts

Food security is a major concern when considering biofuels. The most vulnerable population is also the one mainly depending on local agriculture. Food insecurity is generally caused by poverty, in terms of income, access to education, agricultural resources, technology and credit lines for food production. Thus, rural development is an important path towards a reduction in poverty and food insecurity. Countries with land potential for biofuels have significant possibilities for developing their agricultural sector, increasing their income and substantially improving the population's living conditions [49]. Burkina Faso is an agricultural country with more than 80% of its population fully dependent on agriculture. Farmers could raise their standard of living by producing oil crops in their fields [50].

A recent life cycle assessment (LCA) study focusing on West African conditions and *J. curcas* biodiesel production announced a 72% reduction in greenhouse gas emissions (GHG) compared with conventional diesel fuel (from agricultural production to biodiesel storage) [70]. According to the scenario elaborated in this study, RVO from *J. curcas* sold directly on local markets would reduce GHG emissions by 45% [70]. In fact, direct use of the oil does not change GHG emissions from *Jatropha* cultivation, but it does reduce to a larger extent the energy consumption of the process, because neither transesterification nor transportation for export is necessary. These results illustrate robust opportunities and high potential for *Jatropha* to attract carbon credits from the Clean Development Mechanism (CDM) or the voluntary market [57], especially in sub-Saharan Africa. These results in West Africa can mostly be explained by the perennial nature of the crop and by a decentralized, non-motorized and low-input production system.

Biofuel activities would directly and keenly affect communities in which they are located [71]. Best-case scenarios may envisage biofuels as the major source of quality employment, providing energy services at an acceptable price, while giving rise to environmental benefits such as carbon reductions, land restoration, and watershed protection. On the other hand, one can also imagine worst-case scenarios. Crop production may lead to further consolidation of land holdings, land-use conflicts in food production, displacement of existing livelihoods and negative environmental effects. Thus, developed countries implementing biofuel programmes must be careful in order to avoid welfare losses [53].

5.2. Profitability of biofuels

Biofuel activities necessarily call for labour-, resource- and land-intensive undertakings, but this should not be a problem for Burkina Faso, a country with a large agricultural population and with substantial land availability.

In the literature, the economic competitiveness of fossil fuels is a very common argument against renewable energies and biofuels in particular, even though the costs of producing biofuels in developing countries are very near to the world market price of petroleum fuel [44]. Biofuel production costs can vary widely depending on the feedstock, conversion process, scale of production and region, and use of presscake (livestock feed, manuring, etc.), which is why financial burdens are difficult to determine globally. At the moment, the cost of producing biofuels is often significantly higher than the cost of producing fossil fuels [53,72]. However, the gap is expected to narrow with the current hike in the price of oil and given the 30% extra cost for oil in Burkina Faso due to storage and transportation [38]. The costs could also probably decline in the future, especially if it is produced by family farming even on an industrial scale, and with easy processes like RVO technologies, because no transesterification with costly processes and components is required and only few investments are necessary to develop this scenario. In the electricity or shaft power scenario, many conditions are combined in Burkina Faso to produce RVO at the same price as or cheaper than fossil fuels. In any event, if we consider the potential added value for agricultural products and the national economy, this RVO strategy appears to be profitable in the short term. Nevertheless, promotion measures are essential for ensuring substantial domestic biofuel production and demand. These promotion measures are justified by their proponents as a source of environmental benefits, fostering the security of energy supplies, and leading to job creation in the agricultural sector [53].

The “economic mechanisms” in operation here are: (1) linking commercial demand for traditional and modern fuels with the existing potential local capacity (land, labour, water, knowledge, etc.) to produce alternative modern fuels; and (2) re-orienting the financial resource flows away from “commodity purchase” (energy imports) towards “capital investments” (biofuel production facilities) and “welfare” build-up (employment and income generation).

5.3. Impacts on macroeconomics

A diversification of energy sources with biofuels could save on the expenditure going to oil companies and moderate fuel imports, while increasing the benefits for households, firms and administrations. Moreover, this could change unproductive products, because imported, into products that generate national income and employment.

According to the Burkinese Government, in 2008 overall fossil fuel consumption (575,409 m^3) cost 251 billion CFAF, with only 36 billion considered as national added value creation (14.3%), whereas 215 billion CFAF were needed as foreign currency to pay the fossil fuel bill [22]. This energy consumption generated 87 billion CFAF of taxes (customs levies, taxes on oil and VAT) but 16 billion CFAF were reused to fund electricity production [22].

The biofuel economic structure is diametrically opposed to the imported fuels profile. Indeed, raw material production is an activity mainly generating added value (if it is family farmed), given the very limited energy costs and equipment (from 8 to 10%) [73]. The processing of raw materials to make RVO requires equipment (press, filter, settling equipment, etc.) and an energy consumption that will include some import costs, from 40 to 50% of production costs [73]. However, that percentage could be reduced with centralized processing (oil mill, cooperative, small and medium enterprise, etc.), considering the scale effect and better yields. Thus, processing will generate added value of around 50–60% of production costs. For rural processing, with the use of local small screw-presses powered by local RVO, the added value of the production process could amount to around 80% of production [73].

Table 6
Incomes provided from fossil fuel or biofuel spending [73].

	Fossil fuel	Biofuel
Expenses (€)	1	1
Direct and indirect added value (€)	0.4	1.4–1.6
Taxes on added value (€)	0.07	0.16–0.22
Foreign currency need (€)	0.86	0.26–0.46

Depending on a rural or an industrial scale option for production and processing, biofuel production will require around 16–40% of investment in foreign currency and will generate between 84 and 60% of direct added value in terms of rural incomes, wages, financial expenses, even taxes for the State, and earnings for economic operators [73].

Compared to imported fuels, national biofuel production could create more significant direct added value, helping to increase national GDP [23]. This added value will contribute to rural populations by improving their standard of living and health, thereby increasing their production capacity. Incomes would also be injected into production activities, such as buying equipment, transport and services. These activities contribute indirectly to GDP and generate State earnings with an exponential effect on the economy by boosting subcontracting and finance activities. Economic simulations are roughly developed in Table 6 considering expenses of € 1 of imported fuels or € 1 of biofuels. For instance, the energy expenditure for biofuels generates 3–4 times more national added value, and the taxes on it would be 2–3 times greater than the same expenditure on imported fuels.

6. Conclusion

The government of Burkina Faso has designed a Global Strategy for the Reduction of Poverty, with the fundamental objective of accruing human capital and triggering growth dynamics. It is also meant to enhance the competitiveness of the economy, ensure its smooth integration in the global economy and improve the living conditions of the entire nation in the long term.

Energy plays a critical role in reaching these objectives by providing a vital service necessary for improving the quality of life and boosting economic progress [45]. Woody resources alone may not enable substantially improved growth. Shaft power and electricity are needed to develop industry and agriculture and generate incomes on a local scale.

Ensuring a sustainable energy supply is a key challenge to achieve the MDGs. However, with fossil fuel dependency persisting and without an adequate energy strategy, no sustainable development would be possible. There are many reasons for biofuels to be considered as relevant technologies for sustainable development: energy security reasons, environmental concerns, foreign currency savings, and socio-economic issues related to the rural sector. Biofuel production has significant macroeconomic advantages in terms of reducing the balance of trade deficit, creating direct (increase in GNP) and indirect (impact on national economy and standards of living) added value and creating additional taxes on direct and indirect added value.

The State could also benefit from this scenario, by reducing or slowing down subsidies for electricity production and the running of its administration's operations. Local production and consumption of RVO is a favourable option to boost local potentials, promote investments and create development with accessible technologies and practices in the short term.

However, despite many potential benefits [44], biofuels will not automatically contribute to sustainable development. A sustainable process of local rural economic growth and diversification could gradually be developed with broader poverty alleviation impacts, but only within adequate and socially responsible policy frameworks.

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